

**AGE, WORKING MEMORY, AND THE STRATEGIC CONTROL  
OF ATTENTION AT ENCODING**

A Thesis  
Presented to  
The Academic Faculty

by

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In Partial Fulfillment  
of the Requirements for the Degree  
Masters of Science in the  
School of Psychology

Georgia Institute of Technology  
May, 2011

**AGE, WORKING MEMORY, AND THE STRATEGIC CONTROL  
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Date Approved: February 21, 2011

## **ACKNOWLEDGEMENTS**

I would like to thank my advisor, Dr. Andy Smith, as well as the other members of my committee, Dr. Audrey Duarte and Dr. Paul Verhaeghen, for serving as sources of inspiration and offering their guidance and support. I also wish to thank my colleague, Andrew Kelly, who was invaluable in lending his knowledge of SPSS and analytic techniques. Most importantly, I express my deepest appreciation to my parents, Bob and Gail Hayes, for supporting me throughout this entire process. Without them, I fear none of this would have been possible. I would also like to thank my sister, Dawn Carpenter, for serving as a great source of encouragement, insight, and amusement during my tenure at Georgia Tech.

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## LIST OF SYMBOLS AND ABBREVIATIONS

AOSPAN	Automated Operation Span
SI	Selectivity Index
TBF	“To-Be-Forgotten”
TBR	“To-Be-Remembered”
WMC	Working Memory Capacity



## **SUMMARY**

The current study investigated the effects of aging on the strategic control of attention at encoding and the extent to which this relationship was mediated by working memory capacity. The value-directed remembering task used by Castel et al. (2009) was modified to include an inhibitory task demand (i.e., value-directed forgetting), and age differences were predicted due to declines in the efficiency of inhibitory mechanisms. Results confirmed this prediction, as older adults were less efficient in maximizing their selectivity scores upon the inclusion of task interference, and working memory was found to be supportive of performance. Results additionally support an age-related decline in the directed forgetting effect, such that older adults recalled and recognized fewer TBR items and more TBF items, relative to younger adults. Taken together, results suggest an age-related decline in the ability to inhibit goal-irrelevant information, thereby limiting working memory resources available for greater processing of goal-relevant information.

# **CHAPTER 1**

## **INTRODUCTION**

As proposed by Baddeley and Hitch (1974), working memory is a multi-component, limited capacity workspace capable of monitoring and transforming information while executing complex cognitive tasks. A crucial function of the working memory system is distinguishing between relevant and irrelevant information while maintaining task goals, often in the face of competing or distracting information. Because environmental demands are constantly changing, it is important that the contents of working memory be monitored and updated efficiently. Hasher and Zacks (1988) argue that older adults have deficits in attentional inhibition, thereby allowing more irrelevant information to enter working memory and deplete working memory resources requisite of efficient processing. Impaired inhibition can be a hindrance in everyday situations, for it is often necessary to attend to important information while directing attention away from less relevant information. This relates to the strategic control of attention, or the ability to optimally direct attentional resources and selectively encode high-value information (Castel, Balota, & McCabe, 2009).

Using value to guide cognitive resources towards important information can be considered an efficient use of memory, especially given the abundance of information in our surroundings. Consider, for example, wanting to remember the birthdays of loved ones. Although it is unlikely to remember the birthdays of every person one's ever known, being able to remember the birthdays of one's parents or grandchildren, for example, can be considered a value-guided, efficient use of memory. Furthermore, one's capacity to inhibit distracting interference (or irrelevant information) is essential to using memory resources and attention in an efficient, goal-directed manner. It is often necessary to forget certain information, for it may no longer be relevant to current

environmental or task demands. For example, consider a change in one's dosage of medication. One must disregard the previous instruction to take 1 pill every 4 hours and must now remember to take 1 pill twice a day. This requires inhibition of previously relevant information alongside maintenance of the newly relevant information.

To investigate age-related changes in the strategic control of attention, Castel and colleagues (2009) used a value-directed remembering task, wherein selective encoding was operationalized as encoding high-value stimuli in alignment with task goals. Participants were presented with a list of words, and each word was paired with a distinct point value. Participants were instructed to remember as many words as possible, with the goal being to selectively encode high-value words in order to maximize their total score. Castel and colleagues then calculated a selectivity index for each participant by dividing their actual score by an ideal score based upon the number of words recalled.

Results indicated that older adults were equally as selective as younger adults when encoding high-value items, albeit at a cost of being able to recall fewer low-value items (Castel et al., 2009). However, it is possible that the task did not pose sufficient attentional demands to evaluate age-related changes in executive functioning, as participants merely needed to remember 3-4 of the highest value words in order to obtain optimal selectivity. This tempers the finding that older adults perform comparably to younger adults when strategically controlling attention at encoding, as the task may not have adequately recruited controlled attention.

Attentional control impairments have been associated with impairments in maintaining relevant information in working memory while limiting activation of irrelevant information, and research suggests these impairments increase with age (Hasher & Zacks, 1988). It is important to note that these inhibitory, attentional control mechanisms operate to narrow the focus of the working memory system and boost the efficiency of this system (Hasher, Zacks, & May, 1999). In the current study, the value-directed remembering task used by Castel et al. (2009) was modified to include an

inhibitory task demand. More specifically, participants must now inhibit the processing of irrelevant negative-value words while selectively maintaining activation of high-value words.

The inclusion of negative-value items bears semblance to directed forgetting tasks, such that negative-value words are considered “to be forgotten.” By including irrelevant negative-value words (i.e., introducing a condition of task interference), participants must inhibit the processing of these items while maintaining activation of task-relevant items. In accord with Hasher and Zacks (1988) inhibitory deficit hypothesis, age differences were expected due to declines in the efficiency of inhibitory mechanisms. This diminished efficiency may result in greater intrusion of task-irrelevant (i.e., negative-value, “to-be-forgotten”) items, thereby cluttering the working memory space and limiting resources available for processing goal-relevant stimuli.

### **Working Memory and Controlled Attention**

The original working memory model proposed by Baddeley and Hitch (1974) consists of three components: the central executive and two "slave" systems, namely the phonological loop and visuo-spatial sketchpad. The central executive is thought to coordinate working memory and is largely responsible for tasks requiring attentional control, planning, and the selection/inhibition of stimuli (Baddeley, 1996). The primary functions of the central executive can be divided into three components: inhibiting distracting interference, shifting between concurrent task demands, and updating contents of working memory. The inhibition function, of most relevance to the current study, involves using attentional control to maintain selective access to information needed to complete a given task or goal (Friedman & Miyake, 2004).

Controlled attention reflects one’s ability to effectively maintain task goals and task-relevant stimuli in working memory while inhibiting interference or irrelevant stimuli (Kane, Bleckley, Conway, & Engle, 2001). Conway and Engle (1994) suggest

that individual differences in working memory capacity (WMC) are primarily a reflection of one's capacity for controlled processing. Research further suggests that individual differences in controlled attention are largely responsible for the association between working memory span measures and performance on complex cognitive tasks (Kane et al., 2001). A task sensitive to differences in working memory, the Stroop task, requires participants to name the color of color-word stimuli when these two aspects are congruent (e.g., occurrences when the word 'GREEN' is presented in green ink) or incongruent (e.g., occurrences when the word 'GREEN' is presented in red ink). Word information generally interferes with color naming, leading to an increase in error rate and response time on incongruent trials (Stroop, 1935). Controlled attention is thought to support performance of the Stroop task by maintaining task goals (i.e., proper naming of color) in the face of interfering information (i.e., incongruent word context).

McCabe, Robertson, and Smith (2005) further explored the relationship between WMC and controlled attention by adding a span element to the traditional Stroop task. Not only must participants make decisions based on color-word congruency, participants are also asked to recall (in order) the colors that were presented in each series. In comparison with younger adults, McCabe and colleagues predicted that older adults would show more errors in the Stroop span task, with the number of errors increasing as memory load increased. Additionally, older adults were predicted to have a disproportionately large number of incongruent color-word errors relative to congruent color-word errors, reflecting a greater susceptibility to task interference. These predictions were confirmed, as performance on measures of WMC and executive functioning were inversely related to errors on the Stroop span task for older adults. Incongruent word errors also increased with an increase in memory load for older adults, reflecting a deficiency in allocating proper attention to task demands (McCabe et al., 2005). This served to further support the linkage between WMC and controlled attention.

Kane et al. (2001) suggest that individual differences in WMC are most relevant to higher-order cognition in the face of interference, and the current study imposed a condition of task interference to highlight this relationship. Research suggests interference impairs cognitive processing, and individuals with greater WMC are more effective in maintaining activation of task-relevant information while inhibiting distracting interference, relative to individuals with lesser WMC (Kane & Engle, 2003; McCabe et al., 2005). According to the controlled attention framework, goal maintenance processes involved in executive functioning challenge one's working memory system. Specifically, keeping task goals active in working memory requires controlled attention, and this process will break down as competition for limited attentional resources increases (Kane et al., 2001). Thus WMC was expected to mediate performance in the current study, as the modified value-directed remembering task introduces a condition of task interference and requires controlled attention in maintaining selective encoding of task-relevant stimuli.

### **Inhibition**

Inhibition generally refers to the suppression of interfering stimuli or impulses and can be divided into three primary components: resistance to distractor interference, resistance to proactive interference, and prepotent response inhibition (Friedman & Miyake, 2004). Of particular relevance to the current study is resistance to distractor interference, which reflects one's ability to resist or suppress interference from task-irrelevant stimuli. As individual differences in WMC are related to differences in controlled attention capabilities, tasks requiring the inhibition of distracting interference are expected to highlight this relationship. Additionally in tasks of inhibition, older adults tend to show greater susceptibility to task interference (McCabe et al., 2005; Zacks & Hasher, 1997). Given that measures of executive control are most valid when the task imposes high attentional demands (Rabbitt, 1997), the value-directed remembering task used by Castel et al. (2009) was modified to increase attentional demands and impose

distracting interference upon the central executive. Tasking participants to inhibit irrelevant information requires greater controlled attention and was expected to be particularly detrimental for older adults, relative to younger adults. This contrasts with Castel et al. (2009), who found no age differences in the ability to strategically control attention at encoding.

### **Inhibitory Deficit Hypothesis**

Hasher and Zacks (1988) suggest normal aging is accompanied by declines in the efficiency of inhibitory mechanisms, thereby hindering older adults' ability to optimally select what items to maintain in working memory. Evidence of age-related impairments in attentional inhibition can be found in tasks where older adults are forced to inhibit distracting interference while maintaining focus of relevant task goals. The aforementioned Stroop span task provides evidence of this, as older adults showed greater susceptibility to task interference, with this susceptibility increasing alongside an increase in memory load (McCabe et al., 2005). Selection tasks, wherein participants must attend to a goal-relevant target item in an array of distractors, also assess attentional inhibition.

Hartman and Hasher (1991) employed a selection task to investigate age-related differences in inhibitory processing. Older and younger adults were given a set of sentences, each missing its final word, and were instructed to predict the final word of the sentence. Half of their predictions (consisting of highly probable endings) were confirmed, and half of their predictions were disconfirmed. Upon disconfirmation, the target ending (consisting of a plausible, yet unexpected word) flashed on the screen. Participants were instructed to remember only target words and to ignore all disconfirmed, self-generated endings. Experimenters then assessed memory for target words as well as for disconfirmed distractor words. Based on the logic that older adults would have difficulty inhibiting activation of the disconfirmed words, Hartman and

Hasher predicted diminished performance for older adults. Results aligned with Hasher and Zacks' (1988) inhibitory deficit hypothesis, such that older adults were impaired in their ability to prevent disconfirmed, irrelevant words from gaining access to working memory. When tested for memory of target and distractor words, younger adults showed retention only of target words whereas older adults showed retention of both the target and the disconfirmed, distractor words (Hartman & Hasher, 1991). This suggests younger adults were able to delete these items from working memory (thereby freeing up additional working memory resources), whereas older adults generally failed to prevent these items from retaining access.

### **Directed Forgetting**

Directed forgetting reflects one's ability to prevent task-irrelevant information from interfering with the memory of task-relevant information. Directed forgetting is typically studied using either item-method or list-method approaches, with the item-method approach being most relevant to the current study. In the item-method approach, participants are presented with words one at a time and then subsequently instructed whether to remember or forget the word. Each word is categorized as either "to-be-remembered" (TBR) or "to-be-forgotten" (TBF). In the list-method approach, participants are presented with an entire list of words and then given instructions to remember or forget the previously-presented list. Participants are then given a new list to remember, and the cycle is variably repeated (Basden, Basden, & Gargano, 1993; Sego, Golding, & Gottlob, 2006).

The directed forgetting effect (i.e., superior recall of TBR items, relative to TBF items) is established during tests of recall for both the list- and item-method approaches (Sego et al., 2006). However, it is suggested that different cognitive mechanisms operate within each approach, as results dissociate across recall and recognition tasks. In the item-method approach, participants tend to perform equivalently on tests of recall and



recognition (i.e., recalling and recognizing the same TBR and TBF items). However in the list-method approach, the directed forgetting effect is eliminated at recognition (with more TBF items now being recognized than were previously recalled). Research suggests this list-method effect is indicative of selective retrieval, such that participants inhibit previously-encoded TBF word lists at recall and selectively retrieve only TBR word list items. Research suggests items within each list are encoded using a type of relational processing, such that all items in a single list are encoded and rehearsed together in a lump-sum fashion (Basden et al., 1993; Sego et al., 2006). That is, participants likely encode entire word lists equivalently with elaborative rehearsal prior to the list being designated as TBR or TBF. Although retrieval inhibition is thought to suppress TBF lists at recall, this inhibition is then released when participants see the words again during recognition. Because these list items were sufficiently encoded prior to their TBF designation, they are now equally as available as TBR items, thereby eliminating the directed forgetting effect at recognition in the list-method approach.

Alternatively, research suggests processing within the item-method approach is indicative of selective encoding, such that TBR and TBF items are differentially encoded according to their individual cue designation. That is, TBR items receive additional processing, whereas TBF items are dropped from active memory upon cue assignment. Recognition performance is equivalent to recall performance in the item-method approach, such that words recognized or recalled are solely those words that were further encoded. Individual (as compared to relational) processing is thought to operate during the item-method approach, as the decision to encode each word is made on a case-by-case basis in accordance with its TBR or TBF assignment. Research suggests that TBR items receive greater processing relative to TBF items, which allows the directed forgetting effect (i.e., greater recall of TBR items, relative to TBF items) to remain intact during both implicit and explicit tests of memory (Basden et al., 1993; Sego et al., 2006; Titz & Verhaeghen, 2010).

In line with the inhibitory deficit hypothesis (Hasher & Zacks, 1988), older adults are expected to show a reduction in the directed forgetting effect, relative to younger adults. Zacks and colleagues suggest that older adults are less efficient at inhibiting the processing of TBF items, thereby depleting their capacity (relative to younger adults) to selectively encode TBR items (Zacks, Radvansky, & Hasher, 1996). Although there have only been a limited number of studies with regard to directed forgetting and aging, prior research suggests reduced directed forgetting for older adults, relative to younger adults (Andrés, Van der Linden, & Parmentier, 2004; Zacks et al., 1996). Younger adults typically recall a greater number of TBR items, whereas older adults tend to recall a greater number of TBF items. The likelihood of TBF recall for older adults is further increased when the test block contains a large proportion of TBR items, which (much like a block within the Stroop task containing mostly congruent color-word trials) requires persistent maintenance of task goals (Zacks et al., 1996).

In an attempt to further investigate age-related inhibitory impairments, Andrés et al. (2004) manipulated the level of task interference to see if the directed forgetting effect (obtained by Zacks et al., 1996) would be magnified by an increase in task demands. Andrés and colleagues tasked participants with recalling trigrams (i.e., a compilation of three letters) and compared results across age groups in three conditions. The three conditions were as follows: either the trigram was presented alone (control condition), the trigram was followed by a second trigram to be recalled individually (interference condition), or the trigram was followed by a second trigram to be forgotten (directed forgetting condition). Results aligned with Hasher and Zacks' inhibitory deficit hypothesis (1988), such that older adults were less efficient at inhibiting the processing of TBF trigrams. Older adults were also increasingly sensitive to distracting interference (as indexed by results from the interference condition), relative to younger adults.

Although Andrés et al. (2004) and Zacks et al. (1996) provide support for age-related deficits in directed forgetting, Sego et al. (2006) found that older and younger

adults had equivalent levels of TBF recall and suggest that the reduction in directed forgetting for older adults is a result of younger adults recalling a larger number of TBR items. The equivalency of TBF recall between older and younger adults contradicts the inhibitory deficit hypothesis and warrants further exploration. The current study incorporates directed forgetting (as the inhibitory component) within a value-directed remembering task and predicts an age-related decline in directed forgetting due to declines in inhibitory efficiency. Given that the item-method approach will be used, a reduction in directed forgetting is expected to be indicative of impaired efficiency operating at the encoding stage of processing, and recognition findings are expected to help confirm this prediction.

### **Strategic Control of Attention**

Selectively attending to high-value information in light of capacity limitations and later recalling this information can be thought of as one's strategic control of attention (Castel, 2007). Across numerous variants of the value-directed remembering task, Castel and colleagues found that older adults are equally as capable as younger adults when selectively encoding high-value information (Castel, Benjamin, Craik, & Watkins, 2002; Castel, Farb, & Craik, 2007). Castel and colleagues further claimed that older adults exercised control in limiting attention to lower-value items while maintaining activation of the 3-4 highest value items (Castel et al., 2002). Given that age differences are typically found on tasks requiring controlled processing (McCabe et al., 2005; Park et al., 1996), the findings from Castel and colleagues (2002, 2007, 2009) were particularly surprising.

In Castel et al. (2009), *memory efficiency* is defined as the strategic use of memory despite capacity limitations, and researchers were interested in whether individual differences in WMC would be related to efficient encoding of high-value items. Castel and colleagues administered a variant of the value-directed remembering

task, wherein participants were presented with a list of words ranging in point values from 1 to 12. A selectivity index was calculated for each participant by dividing their actual score by an ideal score based upon the number of words recalled. The selectivity index ranges from -1.0 to +1.0 and is calculated as follows:  $(\text{participant's score} - \text{chance score}) / (\text{ideal score} - \text{chance score})$ . However, a more refined look at the selectivity index suggests that it may be biased in favor of remembering fewer words overall, thereby penalizing younger adults for recalling additional items. Therefore, the absence of age-related differences in selectivity may be due, in part, to the dilution of younger adults' scores for recalling a greater number of items.

Consider a participant who recalls **three** words valued: 11, 10, and 7. The ideal score for recall of three items is  $12 + 11 + 10 = 33$ , and the participant's score = **28**. The chance score reflects what score would be obtained by chance and equals the average score (which for a list of 12 words equals 6.5) multiplied by the number of words recalled (3). Thus the chance score, in this case, equals **19.5**. The selectivity index for the above exemplar =  $(28 - 19.5) / (33 - 19.5) = .630$ . Now consider another participant who recalls **six** words valued: 11, 10, 7, 5, 4, and 3. Note that the three highest values are identical for both participants, yet the selectivity index for the second participant (more characteristic of a younger adult) =  $(40 - 39) / (57 - 39) = .055$ .

As can be seen, the selectivity index employed by Castel et al. (2002, 2007, 2009) is biased in favor of lesser total recall. This bias stems from the use of an "ideal score," which reflects one's perfect score based upon the number of words recalled for that particular word list. For example, the "ideal score" for a participant recalling three words would be 33 (i.e.,  $12 + 11 + 10$ ). However as a greater number of words are recalled, the "ideal score" increase, thereby inflating the denominator and diluting one's selectivity index (SI) as a result.

In order to address this concern, the current study calculated a modified SI for each participant, such that the "ideal score" remains constant across all participants. This

score reflects a score of perfect performance (i.e., perfect recall of all 12 TBR items). Thus the “ideal score” for each participant remained at a value of 78, and this resulted in a more strict SI across both age groups. A summed score was also calculated for each participant, such that the point values of all recalled words were summed for each word list. By summing the total number of points for recalled words, a straightforward measure of value-directed remembering is obtained. It is still more beneficial to remember four words valued 11, 10, 9, and 8 than it would be to remember four words valued 5, 4, 3, and 2, yet it would be even more beneficial to remember five words valued 11, 10, 9, 8, and 4. The selectivity index used by Castel et al. (2002, 2007, 2009) was also included for ease of comparison.

Castel et al. (2009) found that while older adults recalled fewer items overall, they were efficient in obtaining selectivity indices comparable to younger adults. In breaking down performance, healthy older adults typically recalled 3-4 of the highest-value items, albeit at a cost of recalling fewer lower-value items, relative to younger adults. Individuals with Alzheimer’s disease also recalled more high-value than low-value items but failed to efficiently maximize performance (as measured by their selectivity index), relative to healthy older adults. In order to infer, however, that there are no age-related declines in the ability to strategically control attention, it is imperative that the task pose sufficient attentional demands to measure age-related changes in executive functioning.

### **Task Modifications**

To increase attentional demands in the current study, word lists were lengthened from 12 words (as per Castel et al., 2009) to 18 words. Point values within each list ranged from -6 to +12, such that words valued -6 to -1 posed a condition of task interference and must be inhibited for optimal performance. The inhibitory component incorporates directed forgetting within the value-directed remembering task, such that words valued -6 to -1 can be considered TBF, whereas words valued +1 to +12 can be

considered TBR. In line with Hasher and Zacks' (1988) inhibitory deficit hypothesis, older adults were expected to have greater difficulty inhibiting the processing of TBF items while maintaining activation of higher-value items. To further explore this relationship, TBF items in the experimental condition were selected to be particularly distracting (as evidenced by prior research). The distracting dimensions incorporated within the current study were twofold: arousal (how calming or stimulating an item is) and valence (how positive or negative an item is). Both dimensions have been suggested to garner processing priority and thus were expected to increasingly challenge the working memory system of participants when serving as distracting stimuli (Kensinger & Corkin, 2003; Minnema & Knowlton, 2008).

### **Arousal Theory**

Research suggests that arousing stimuli consume cognitive resources requisite of efficient processing and are encoded more strongly than neutral stimuli (Dewhurst & Parry, 2000; Kensinger & Corkin, 2003). Arousing stimuli are also suggested to be perceived as distinctive when presented in mixed lists with neutral items, and research suggests distinctive items are increasingly salient, receive processing priority, and consume more processing resources, relative to less distinctive items (Dewhurst & Parry, 2000). Attentional biases toward emotional stimuli could have a negative impact on working memory performance, as has been found with regard to the emotional Stroop task (Dresler, Mériaux, Heekeren, & van der Meer, 2009). Participants are typically slower to name the color of ink for an emotional word relative to a neutral word, indicating an attentional consumption by such stimuli.

Similar to findings of the emotional Stroop task, MacKay et al. (2004) found that participants were slower to name the color of ink for taboo words, relative to neutral words. When given an unexpected recall test upon completion, participants demonstrated

superior recall of taboo words, relative to neutral words. Furthermore, participants demonstrated superior recall of font colors associated with taboo words, and MacKay et al. (2004) suggest this reflects enhanced associative binding of emotional stimuli. That is, taboo words trigger an emotional reaction that distinguishes the experience and triggers binding mechanisms to link the word to its context (in this case, font color). Results additionally suggest impaired recall of neutral words that were presented immediately before or after taboo words.

MacKay and colleagues (2004) suggest that taboo words abruptly dominate cognitive mechanisms, thereby hindering the encoding and retrieval of neighboring neutral words. This is relevant to the current study in that emotionally arousing stimuli were predicted to consume cognitive resources requisite of efficient processing and impair performance when serving as distracting stimuli (i.e., TBF items). Accordingly, all TBF items in the experimental condition were selected to have high-arousal means (as measured by the Affective Norms for English Words (ANEW) database; Bradley & Lang, 1999) and were expected to challenge the inhibitory system of participants and contribute to greater age-related differences in selectivity.

In addition, valence was manipulated in the current study, such that each word list consisted of an equal proportion of positive and negative items. Assuming emotional stimuli recruit attention and are encoded in a more distinctive manner, it was expected that arousing stimuli with a high positive or negative valence would garner processing priority over neighboring neutral items. Manipulating TBF items in the experimental condition to consist solely of arousing words with a high positive or negative valence was expected to challenge inhibitory capacities while also allowing for an investigation of age-related attentional biases towards items of a particular valence. Previous research suggests that older adults exhibit attentional biases towards positive items, whereas younger adults have been found to exhibit attentional biases towards negative items (Mather & Knight, 2005; Thomas & Hasher, 2006). However, findings have been mixed

in this regard (Grühn, Smith, & Baltes, 2005; Kensinger, Brierley, Medford, Growdon, & Corkin, 2002), and controlling for valence in the current study allowed for a post hoc examination of potential age-related attentional biases.



## **CHAPTER 2**

### **EXPERIMENT 1: MODIFIED VALUE-DIRECTED REMEMBERING TASK**

#### **Method**

##### **Participants**

Forty-eight younger adults ( $M = 19.81$ ,  $SD = 1.44$ ) and 48 older adults ( $M = 69.69$ ,  $SD = 5.15$ ) were included in the sample. Younger adults were recruited from the undergraduate population at Georgia Tech and received 1.5 hours of course credit for their participation. Older adults (all of whom live independently in metropolitan Atlanta and were capable of making their own way into the laboratory) were recruited from the laboratory database and were compensated \$15 for their time. All participants were native English speakers and reported themselves to be in good health. Information about the final sample is included in Table 1.

Table 1: Demographic, Working Memory, and Processing Speed Variables.

VARIABLE	AGE GROUP	
	<u>Younger Adults</u>	<u>Older Adults</u>
N	48	48
Age	19.81 (1.44)	69.69 (5.15)
Education	13.69 (1.29)	16.00 (2.87)
Health	4.23 (0.66)	3.98 (0.978)
AOSPAN	59.12 (12.59)	35.15 (21.91)
Stroop Span	43.46 (7.41)	30.40 (8.87)
Processing Speed	32.957 (4.87)	23.522 (5.54)

*Note.* Standard deviations are enclosed in parentheses. Stroop span and AOSPAN reflect total number of correct items. Processing speed reflects total number of correct items (averaged across pattern, letter, and number comparison worksheets).

## Materials

Two-hundred and thirty-four words were selected as stimuli from the ANEW database (Bradley & Lang, 1999). In the ANEW database, words are normatively ranked for arousal on a scale of calm to stimulating, and words are normatively ranked for valence on a scale of positive to negative. One-hundred and fifty-six words have neutral-arousal and neutral-valence means, 39 words have high-arousal and positive-valence means, and 39 words have high-arousal and negative-valence means. All stimuli were matched for characteristics of word length, concreteness, arousal, and valence.

Controlling for mean levels of arousal and valence allowed for an investigation of each dimension independent of the other and was designed to minimize potential confounding effects of stimulus attributes.

## **Design**

The current study is a 2(age: young, old) x 2(list-type: control, experimental) mixed-factorial design with age serving as the between-subjects factor and list-type serving as the within-subjects factor. In modifying the value-directed remembering task used by Castel et al. (2009), each word list was lengthened from 12 words to 18 words. Point values ranged from -6 to +12. For discussion purposes, words valued -6 to -1 are considered TBF, whereas words valued +1 to +12 are considered TBR. The value-directed remembering task consisted of 13 word lists: one practice list, six control lists, and six experimental lists.

All control and experimental lists contained the same ratio of neutral vs. arousing words (2:1). That is, each word list contained 12 neutral-arousal words and six high-arousal words. Of these six high-arousal words, three were positively-valenced and three were negatively-valenced. The control and experimental conditions differed solely in their assignment of these items. In the experimental condition, all high-arousal items were assigned to values -6 to -1, and thus deemed TBF. The items were intended to serve as distracting interference. All neutral-arousal words were assigned to values +1 to +12 and were considered TBR. In the control condition, all words were randomly assigned to point values, such that high-arousal and neutral-arousal words were equally likely to appear in any of the 18 positions. The control condition was intended to prevent participants from generating a strategy of inhibiting or ignoring any word that seemed arousing or distinct. Words were presented in random order for both the control and experimental conditions.

## **Procedure**

All participants were tested in a single session lasting approximately 90 minutes. Participants were invited into the testing room and completed a demographic questionnaire following informed consent. Task ordering was as follows: 1) modified value-directed remembering task; 2) recognition task; 3) Automated Operation Span task; 4) processing speed worksheets (i.e., letter, pattern, and number comparison worksheets); 5) Stroop span task.

In the modified value-directed remembering task, participants were told they would be studying lists of words, and each word would be paired with a point value, ranging from -6 to +12. All words and numbers were presented on the center of a computer screen in black Times New Roman 48-point font on a white background. Each word remained on the screen for three seconds and was immediately followed by its point value (shown separately for two seconds). Participants were told that the number following each word is its point value, and that the point value indicates how important it is to remember that word (with -6 being the lowest-value and +12 being the highest-value). Participants were told their task is to try to get as many points as possible, and this can be accomplished by remembering as many of the high-value words as they can. Participants were told that words valued +1 to +12 would help their score, with +12 helping their score the most. Participants were told that words valued -6 to -1 would hurt their score, with -6 hurting their score the most.

After each word list, participants were instructed to wait for the word 'RECALL' to appear on the screen (imposing a delay of 10 seconds). Participants were then asked to write down as many words as possible to maximize their total score. Participants were invited to ask questions about the testing procedure and then began a practice list and recall session. After the practice session, participants were again invited to ask questions before continuing with the experiment. The testing session consisted of 12 test trials. Presentation order of the first 10 trials was randomized between experimental and control

conditions, and the presentation structure was manipulated to ensure that the final two test trials consisted of one experimental list and one control list.

After recall for each of the final two word lists, participants were additionally asked whether there were any words they remembered but chose not to write down because they knew it would hurt their score. This was included as a measure of retrieval inhibition and was intended to measure possible age-related differences in selective encoding vs. retrieval inhibition operating within the item-method approach. As evidenced by the directed forgetting literature, selective encoding is thought to operate during the item-method approach (Basden et al., 1993). However, it may be the case that older adults allow a greater proportion of TBF words to enter working memory and then willfully inhibit these items at retrieval, thereby limiting capacity to recall a greater number of TBR items. Recall and recognition findings were expected to help clarify this relationship.

Upon completion of all 12 test blocks, participants were given a computerized recognition test consisting of 96 words. Half of the words (48) were randomly selected from previous test trials, with proportions representative of TBR/TBF proportions used during test (i.e., 16 TBF items, 32 TBR items). The proportions were also maintained with respect to the proportions of arousal and valence employed during recall. The other half of the recognition words (48) were new, unused words from the ANEW database, again matched for characteristics of concreteness, word-length, arousal, and valence. The following question appeared on the computer screen above each word: “*Did this word appear in ANY of the previous trials?*” Participants were asked to respond as quickly and accurately as possible by pressing either ‘Y’ (yes – old word) or ‘N’ (no – new word).

As an index of speed of processing, all participants completed the following timed worksheets: letter comparison, pattern comparison, and number comparison (Salthouse & Babcock, 1991). Participants were given 30 seconds per page to decide whether pairs of letters, patterns, or numbers were the same or different. There were a total of six pages

across the three comparison worksheets, and scores reflect the total number of correct responses obtained in the allotted time.

To obtain measures of WMC, participants completed the Automated Operation Span (AOSPAN) task (Unsworth, Heitz, Schrock, & Engle, 2005) and the Stroop span task (McCabe et al., 2005). The AOSPAN task requires participants to compute math problems (competing against their average computational time and then making T/F decisions regarding the accuracy of the presented solution) while also remembering a string of letters presented individually in between math problems. The participant must then recall letters in their order of presentation.

In the Stroop span task, participants make color-word decisions based on congruency and are then asked to recall (in order) the colors presented in each trial. Each test block consisted of three color-word test trials, and the number of color-word decisions in each trial increased linearly from one to six as the task progressed. Lastly, participants were debriefed, compensated, and thanked for their time.

## **Results**

### **Recall and Selectivity**

Recall and selectivity findings are presented in Table 2. For both older and younger adults, selectivity indices did not significantly differ between experimental and control conditions, so data from both conditions were collapsed across all 12 word lists. This created a single test condition, wherein one third of each word list consisted of high-arousal items and two thirds of each word list consisted of neutral-arousal items. The lack of performance differences between the experimental and control conditions is further explored in the discussion section.

Table 2: Recall and Selectivity.

VARIABLE	AGE GROUP	
	<u>Younger Adults</u>	<u>Older Adults</u>
Selectivity Index (SI)	.732 (0.11)	.475 (0.31)
Modified SI	.594 (0.15)	.306 (0.21)
Summed Score	55.420 (9.92)	35.287 (14.49)
Total_Recall	7.946 (1.76)	5.189 (0.65)
Recall_TBR	7.866 (1.79)	4.840 (1.81)
Recall_TBF	.080 (0.13)	.344 (0.50)
Intrusions	.037 (0.062)	.148 (0.162)

*Note.* Standard deviations are enclosed in parentheses. Data are collapsed across all 12 control and experimental word lists. Recall\_TBR equals recall for words valued +1 to +12. Recall\_TBF equals recall for words valued -6 to -1.

As predicted, younger adults recalled a greater number of words, relative to older adults,  $F(1,94) = 62.600$ ,  $MSE = 2.91$ ,  $p < .001$ . However, in contrast to Castel et al. (2002, 2007, 2009), age differences in selectivity were also found. A one-way ANOVA revealed a significant main effect of age, with younger adults demonstrating superior selectivity indices, relative to older adults,  $F(1,94) = 29.231$ ,  $MSE = 0.054$ ,  $p < .001$ . This suggests that upon the inclusion of an inhibitory task demand (i.e., value-directed forgetting), older adults were no longer able to maintain selectivity indices comparable to younger adults.

In considering the probability of recall across different point values, point values were separated into three categories: words valued -6 to -1 were considered TBF, words valued +1 to +7 were considered low-value, and words valued +8 to +12 were considered high-value. A repeated-measures ANOVA with point-value (i.e., TBF, low-value, high-value) serving as the within-subjects factor revealed a significant main effect of age, with younger adults recalling a greater number of low- and high-value items and a lesser number of TBF items, relative to older adults,  $F(1,94) = 64.692$ ,  $MSE = .025$ ,  $p < .001$ . There was also a significant main effect of point-value, with both age groups recalling more low- and high-value items, relative to TBF items,  $F(1,94) = 496.096$ ,  $MSE = .019$ ,  $p < .001$ . These main effects were qualified by a significant Age x Point-Value interaction, such that older adults demonstrated a decline in the directed forgetting effect by recalling more TBF items alongside fewer low- and high-value items, relative to younger adults,  $F(1,94) = 36.036$ ,  $MSE = .019$ ,  $p < .001$ . A graph depicting the probability of recall across all point values is shown in Figure 1.



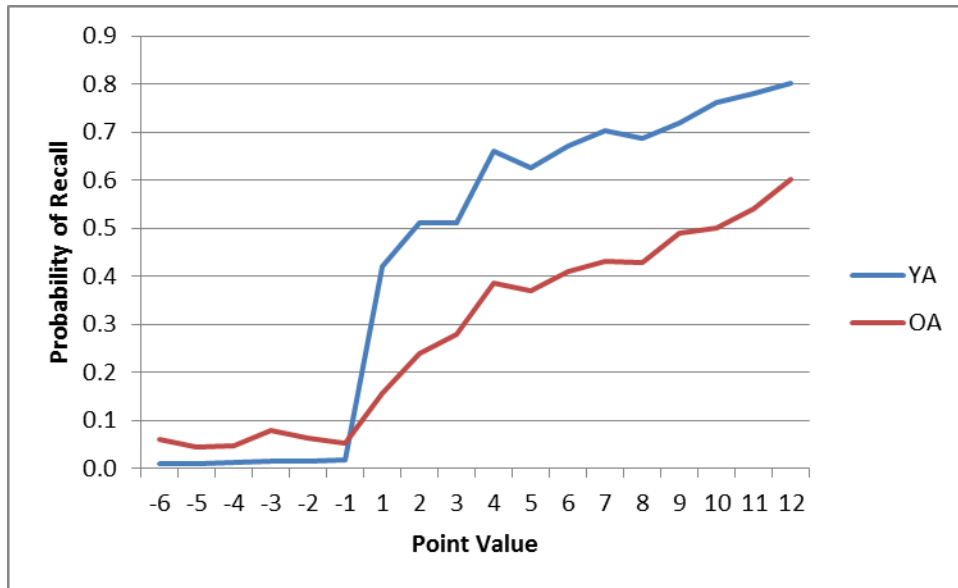


Figure 1: Probability of Recall Across Point Values.

### Additional Indices

In addition to the selectivity index (SI) employed by Castel et al. (2002, 2007, 2009), the current study calculated a summed score and a modified SI for each participant. The summed score is a summation of point values for words recalled within each list and reflects the total value of items recalled. This score serves as a straightforward measure of performance, as it reflects the total value of words recalled and is most consistent with task instructions (wherein participants were asked to maximize their total score).

The initial concern was that the SI employed by Castel et al. (2002, 2007, 2009) was biased in favor of lesser recall, thereby penalizing younger adults for recalling a greater number of items. In order to address this concern, a modified SI was calculated for each participant, such that the *ideal score* remained constant and reflected a perfect score of 100% recall performance (i.e., recall of all 12 TBR items). Thus the *ideal score* equaled 78 for all participants, and this resulted in a diminished SI for both age groups.

However, it is important to note that all findings of significance remained the same regardless of which index was employed as the dependent measure, and thus for ease of comparison with Castel et al. (2002, 2007, 2009), all data are reported using the original SI. Summed score and modified SI data are included in Table 2.

### Arousal

Arousal data are presented in Table 3. In order to take into account younger adults' greater levels of recall, mean proportions of recall for arousing items were calculated as follows: (recall of arousing items / total recall). A one-way ANOVA revealed a significant main effect of arousal, with older adults recalling a greater proportion of high-arousal items, relative to younger adults,  $F(1,94) = 5.034$ ,  $MSE = 0.005$ ,  $p < .01$ . This suggests that high-arousal items may have garnered processing priority in older adults and may have hindered encoding of neighboring, neutral items. In further exploring this main effect, one-way ANOVAs were conducted separately for recall of positive and negative items. Results revealed that the relationship is largely driven by recall of positive items, such that older adults recalled a greater proportion of positive items, relative to younger adults,  $F(1,94) = 7.994$ ,  $MSE = 0.002$ ,  $p < .01$ . There were no age differences in recall of negative items,  $F < 1$ .

Table 3: Recall by Arousal and Valence.

VARIABLE	AGE GROUP	
	<u>Younger Adults</u>	<u>Older Adults</u>
N	48	48
Recall_Arousal	.186 (0.04)	.218 (0.09)
Recall_Positive	.096 (0.03)	.121 (0.06)
Recall_Negative	.090 (0.02)	.097 (0.05)

*Note:* Standard deviations are enclosed in parentheses. Data are collapsed across all 12 control and experimental word lists. Data reflect proportions relative to total recall for each word list.

### **Value-Directed Forgetting Performance**

Data for recall of TBR and TBF items are presented in Table 2. A repeated-measures ANOVA with item-type (i.e., TBR, TBF) serving as the within-subjects factor revealed a significant main effect of age, with younger adults recalling a greater number of items, relative to older adults,  $F(1,94) = 62.782$ ,  $MSE = 1.458$ ,  $p < .001$ . There was also a significant main effect of item-type, with both age groups recalling more TBR items, relative to TBF items,  $F(1,94) = 949.461$ ,  $MSE = 1.907$ ,  $p < .001$ . These main effects were qualified by a significant Age x Item-Type interaction, such that older adults demonstrated a decline in the directed forgetting effect by recalling more TBF items alongside fewer TBR items, relative to younger adults,  $F(1,94) = 68.115$ ,  $MSE = 1.907$ ,  $p < .001$ . This Age x Item-Type interaction for recall is displayed graphically in Figure 2.

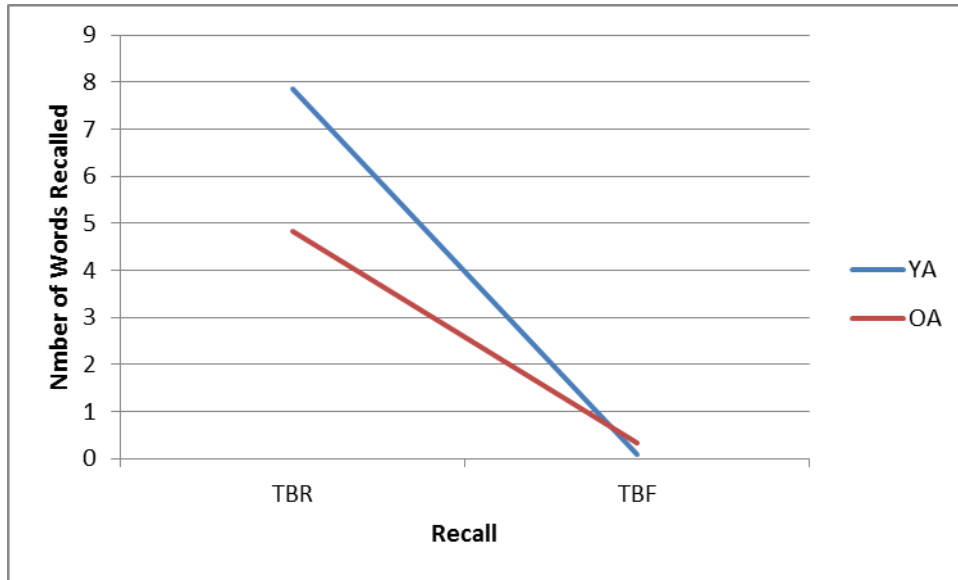


Figure 2: Recall of TBR and TBF Items. TBR = words valued +1 to +12. TBF = words valued -6 to -1.

A one-way ANOVA revealed that older adults had a greater number of intrusions (i.e., mistaken recall of words that were presented in previous word lists), relative to younger adults,  $F(1,94) = 19.826$ ,  $MSE = 0.015$ ,  $p < .001$ . Of these intrusions, older adults mistakenly recalled a greater proportion of negatively-valenced items,  $F(1,94) = 5.727$ ,  $MSE = 0.307$ ,  $p < .05$ , relative to younger adults. This suggests that negatively-valenced items may have remained active in older adults' working memory space and were mistakenly retrieved on later word lists. There were no significant age differences when considering intrusions of positively-valenced items,  $F(1,94) = 2.417$ ,  $MSE = 0.155$ ,  $p > .05$ . Intrusion data are presented in Table 2.

For the final two word lists, participants were additionally asked whether there were any words that they remembered but chose not to write down because they knew it would hurt their score. This measure was included as a measure of retrieval inhibition. No age differences were found,  $F < 1$ , and both groups were near floor in their responses.

This suggests that neither group purposefully withheld items at retrieval and that performance differences were primarily operating at encoding, as would be expected from the directed forgetting literature (Basden et al., 1993; Titz & Verhaeghen, 2010).

### **Recognition**

Corrected recognition data are presented in Table 4. In assessing recognition of TBR and TBF items, recognition scores were corrected as follows: (hits – false alarms). A repeated-measures ANOVA with item-type (i.e., TBR, TBF) serving as the within-subjects factor revealed a significant main effect of age, with younger adults correctly recognizing more items, relative to older adults,  $F(1,94) = 5.034$ ,  $MSE = 0.039$ ,  $p < .05$ . There was also a significant main effect of item-type, with both groups recognizing more TBR items, relative to TBF items,  $F(1,94) = 200.452$ ,  $MSE = 0.015$ ,  $p < .001$ . These main effects were qualified by a significant Age x Item-Type interaction, such that older adults recognized a greater proportion of TBF items and a lesser proportion of TBR items, relative to younger adults,  $F(1,94) = 15.987$ ,  $MSE = 0.015$ ,  $p < .001$ . This Age x Item-Type interaction for recognition is displayed graphically in Figure 3.

Table 4: Corrected Recognition Scores.

VARIABLE	AGE GROUP	
	<u>Younger Adults</u>	<u>Older Adults</u>
N	48	48
Recognition_TBR	.700 (0.15)	.563 (0.156)
Recognition_TBF	.374 (0.17)	.381 (0.186)

*Note.* Standard deviations are enclosed in parentheses. Data are collapsed across all 12 control and experimental word lists. Corrected recognition is calculated as follows: (hits - false alarms). Recognition\_TBR equals recognition of words valued +1 to +12. Recognition\_TBF equals recognition of words valued -6 to -1.

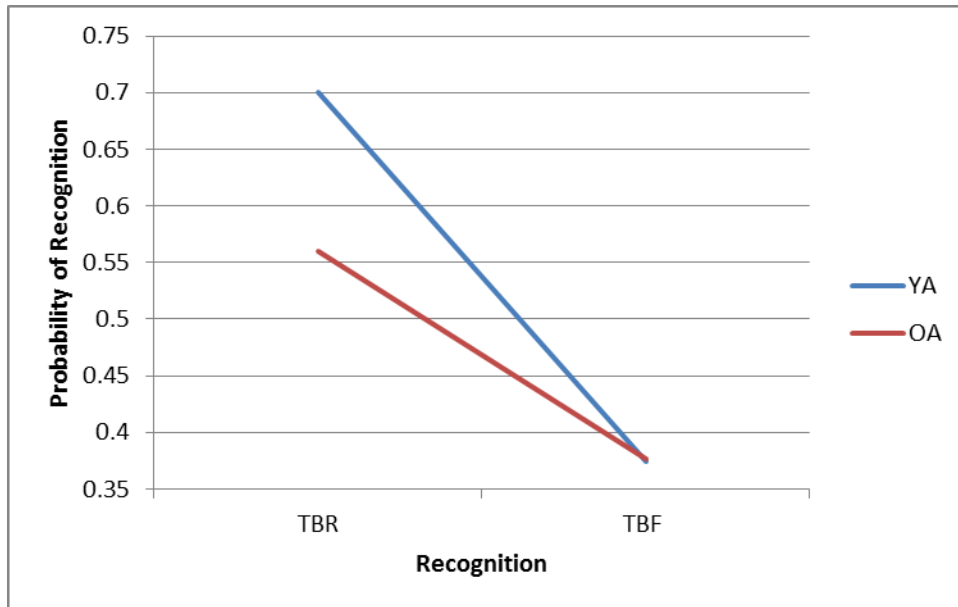


Figure 3: Recognition of TBR and TBF Items. TBR = words valued +1 to +12. TBF = words valued -6 to -1.

## **Working Memory Capacity**

WMC data are presented in Table 1. One-way ANOVAs revealed a significant main effect of age on the Stroop span task,  $F(1,94) = 61.321$ ,  $MSE = 66.781$ ,  $p < .001$ , as well as the AOSPAN task,  $F(1,94) = 42.230$ ,  $MSE = 319.226$ ,  $p < .001$ , with younger adults outperforming older adults in both tasks. The z-scores for both working memory tasks (i.e., AOSPAN and Stroop span) were combined to create a composite variable reflective of WMC. As expected, a one-way ANOVA investigating this composite measure revealed a significant main effect of age, with younger adults outperforming older adults,  $F(1,94) = 73.673$ ,  $MSE = 0.456$ ,  $p < .001$ . This aligns with previous literature suggesting age-related declines in working memory tasks (McCabe et al., 2005; Park et al., 1996).

## **Hierarchical Regression Analyses**

Hierarchical regression analyses were conducted to examine the proportion of variance in selective encoding scores accounted for by WMC, processing speed, and age. A measure of processing speed was included for investigative purposes, as speed of processing has been offered as an explanation for age-related performance deficits in complex cognitive tasks (Salthouse, 1996). Similar to WMC, a composite measure of processing speed was created by combining z-scores for the letter, pattern, and number comparison worksheets. A one-way ANOVA revealed a significant main effect of age, with younger adults outperforming older adults across the three speeded worksheets,  $F(1,94) = 76.191$ ,  $MSE = 27.161$ ,  $p < .001$ . Processing speed data are reported in Table 1.

Hierarchical regression findings are reported in Table 5, wherein selectivity index (SI) served as the dependent measure for both models. In Model 1, the predictor of WMC was entered first, followed by processing speed as the second predictor and age as the third predictor. WMC accounted for a significant proportion of variance in selectivity indices ( $R^2 = .447$ ), whereas the second predictor of processing speed failed to reach significance ( $\Delta R^2 = .010$ ). In Model 2, the predictor of processing speed was entered

first, followed by WMC as the second predictor and age as the third predictor. Processing speed accounted for a significant proportion of variance in selectivity indices ( $R^2 = .253$ ), and the second predictor of WMC additionally accounted for a significant proportion of variance after controlling for the effects of processing speed ( $\Delta R^2 = .204$ ). Importantly, the predictor of age failed to reach significance in either model. Taken together, these findings suggest that age-related differences in selectivity indices are largely mediated by individual differences in WMC.



Table 5: Summary of Hierarchical Regression Analyses.

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Model 1: Working Memory, Processing Speed, and Age

Order	Predictor	$R^2$	$\Delta R^2$	$\Delta R^2$ Sig.
1	Working Memory	.447	.447	$p < .001$
2	Processing Speed	.457	.010	$p > .05$
3	Age	.457	.000	$p > .05$

Model 2: Processing Speed, Working Memory, and Age

Order	Predictor	$R^2$	$\Delta R^2$	$\Delta R^2$ Sig.
1	Processing Speed	.253	.253	$p < .001$
2	Working Memory	.457	.204	$p < .001$
3	Age	.457	.000	$p > .05$

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*Note.* Selectivity Index served as the dependent measure for both models.  $R^2$  signifies the amount of variance in selectivity indices accounted for by that predictor.  $\Delta R^2$  represents the change in variance accounted for due to the addition of another predictor, while controlling for the effects of the other predictors.

## Correlational Analyses

Correlational analyses were conducted to further explore the relationship between WMC and performance. Results for the entire sample ( $N = 96$ ) are presented in Table 6, whereas results for each age group separately ( $n$  (older adults) = 48;  $n$  (younger adults) = 48) are presented in Table 7. In considering the entire sample, there was a significant positive correlation between WMC and SI ( $r = .655, p < .001$ ). There was also a significant negative correlation between WMC and recall of TBF items ( $r = -.536, p < .001$ ), suggesting that WMC is supportive of one's ability to inhibit these items. As expected, WMC was significantly and positively correlated with recall of high-value items ( $r = .701, p < .001$ ), suggesting that WMC is supportive of one's ability to strategically attend to high-value items. This aligns with hierarchical regression findings, such that WMC mediates performance in tasks of selective encoding.

Table 6: Correlations Between WMC, Recall, and Selectivity for Entire Sample.

$N = 96$

	WMC	Recall_High	Recall_Low	Recall_TBF	SI
WMC	----				
Recall_High	.701***	----			
Recall_Low	.595***	.639***	----		
Recall_TBF	-.536***	-.715***	-.353***	----	
SI	.655***	.932***	.484***	-.865***	----

*Note.* Recall\_High equals recall for words valued +9 to +12. Recall\_Low equals recall for words valued +1 to +7. Recall\_TBF equals recall for words valued -6 to -1.

\*\*\*  $p < .001$ .

Table 7: Correlations Between WMC, Recall, and Selectivity by Age Group.

Younger Adults ( $n = 48$ )

	WMC	Recall_High	Recall_Low	Recall_TBF	SI
WMC	----				
Recall_High	.337*	----			
Recall_Low	.353*	.552***	----		
Recall_TBF	-.230	-.502***	-.236	----	
SI	.317*	.924***	.502***	-.648***	----

Older Adults ( $n = 48$ )

	WMC	Recall_High	Recall_Low	Recall_TBF	SI
WMC	----				
Recall_High	.603***	----			
Recall_Low	.325*	.425**	----		
Recall_TBF	-.503***	-.741***	-.253	----	
SI	.569***	.930***	.235	-.875***	----

*Note.* Recall\_High equals recall for words valued +9 to +12. Recall\_Low equals recall for words valued +1 to +7. Recall\_TBF equals recall for words valued -6 to -1.

\*  $p < .05$ . \*\*  $p < .01$ . \*\*\*  $p < .001$ .

In analyzing correlations for each age group separately (Table 7), there was a significant positive correlation between WMC and SI for older adults ( $r = .569, p < .001$ ) and younger adults ( $r = .317, p < .05$ ). This contrasts with Castel et al. (2009), who found a smaller correlation between WMC and SI for older adults ( $r = .22, p < .01$ ) and failed to find a significant correlation between WMC and SI for younger adults ( $r = 0.00, p > .05$ ). The increased correlations in the current study were expected, given the increase in task demands and the increased reliance upon executive functioning.

For older adults, there was also a significant positive correlation between WMC and recall of high-value items ( $r = .603, p < .001$ ), as would be expected from the controlled attention framework. There was also a significant negative correlation between WMC and recall of TBF items ( $r = -.503, p < .001$ ). This suggests that WMC is supportive of older adults' ability to maintain activation of the highest-value items while inhibiting processing of TBF items. Both of these components are necessary for optimal performance, as results indicated a significant negative correlation between SI (i.e., performance) and recall of TBF items ( $r = -.875, p < .001$ ) alongside a significant positive correlation between SI and recall of high-value items ( $r = .930, p < .001$ ).

For younger adults, there was a significant positive correlation between WMC and recall of high-value items ( $r = .337, p < .05$ ), and the correlation between WMC and recall of TBF items was not significant ( $r = -.230, p > .05$ ). However, optimal performance for younger adults still necessitates recall of high-value items and inhibition of TBF items, as there was a significant negative correlation between SI and recall of TBF items ( $r = -.648, p < .001$ ) alongside a significant positive correlation between SI and recall of high-value items ( $r = .924, p < .001$ ). Note the distinction between age groups, such that there was a significant negative correlation between WMC and recall of TBF items in older adults ( $r = -.503, p < .001$ ), whereas this correlation was not significant in younger adults ( $r = -.230, p > .05$ ). This suggests that with increasing age,

WMC becomes a greater source of individual differences when inhibiting distracting interference (i.e., successful non-recall of TBF items).

Additionally, correlational analyses examined the relationship between WMC, performance (i.e., SI), and recognition of TBR and TBF items, and findings are presented in Table 8. For older adults, there was a significant negative correlation between SI and recognition of TBF items ( $r = -.305, p < .05$ ), whereas this relationship was significantly and positively correlated in younger adults ( $r = .289, p < .05$ ). This suggests that for older adults, optimal performance depends upon the efficient inhibition and deletion of TBF items, as was additionally evidenced by a significant negative correlation between SI and recall of TBF items ( $r = -.875, p < .001$ ).

Table 8: Correlations between WMC, Recognition, and Selectivity by Age Group.

Younger Adults ( $n = 48$ )

	WMC	Recognition_TBR	Recognition_TBF	SI
WMC	----			
Recognition_TBR	.370***	----		
Recognition_TBF	.166	.412**	----	
SI	.317*	.236	.289*	----

Older Adults ( $n = 48$ )

	WMC	Recognition_TBR	Recognition_TBF	SI
WMC	----			
Recognition_TBR	.155	----		
Recognition_TBF	-.275	.466***	----	
SI	.569***	.191	-.305*	----

*Note.* Recognition\_TBR equals recognition of words valued +1 to +12. Recognition\_TBF equals recognition of words valued -6 to -1.

\*  $p < .05$ . \*\*  $p < .01$ . \*\*\*  $p < .001$ .

For younger adults, individual differences in performance seem to more greatly stem from the ability to encode a larger number of TBR items, as was evidenced by the significant positive correlations between SI and recall of high- and low-value items ( $r = .924, p < .001$ ;  $r = .502, p < .001$ , respectively). For older adults, there was a significant positive correlation between SI and recall of high-value items ( $r = .930, p < .001$ ), yet the correlation between SI and recall of low-value items was not significant ( $r = .235, p > .05$ ). Differences between age groups were additionally evidenced by the significant positive correlation between WMC and recognition of TBR items for younger adults ( $r = .370, p < .01$ ), whereas this correlation was not significant for older adults ( $r = .155, p > .05$ ). Taken together, this suggests that performance differences in younger adults stem from the ability to encode a greater number of TBR items, whereas performance differences in older adults stem from the ability to encode high-value items while concurrently inhibiting TBF items.



## **CHAPTER 3**

### **GENERAL DISCUSSION**

#### **Value-Directed Remembering**

The primary goal of the current study was to re-examine Castel and colleagues' (2002, 2007, 2009) findings of comparable selectivity between younger and older adults. The value-directed remembering task used by Castel et al. (2009) was modified to increase task demands and more greatly tax the inhibition function of the central executive. By expanding the stimulus set to include TBF items, participants must now inhibit these items while concurrently maintaining activation of valuable TBR items. In other words, optimal performance requires participants to strategically guide their attention towards the encoding of high-value items while suppressing additional encoding of TBF items. The inclusion of an inhibitory task demand requires greater controlled attention and was expected to be particularly challenging for older adults, relative to younger adults. WMC was expected to mediate this relationship, with individuals with greater WMC outperforming individuals with lesser WMC. In this manner, the current study was designed to more closely examine age differences in the strategic control of attention at encoding.

These expectations were confirmed, as younger adults outperformed older adults upon the addition of distracting interference. There was also a decline in the directed forgetting effect, such that older adults recalled and recognized a greater number of TBF items alongside a lesser number of TBR items, relative to younger adults. Together, the findings from the modified value-directed remembering task suggest that the ability to strategically control attention at encoding declines with age. These findings appear to best align with Hasher and Zacks' (1988) inhibitory deficit hypothesis, such that the working memory space of older adults appears to have been increasingly cluttered by a decline in the efficiency in inhibitory mechanisms. Accordingly, a greater amount of

task-irrelevant information remained in active memory, thereby depleting resources for greater processing of task-relevant information. This was evidenced by the significant Age x Item-Type interactions for recall and recognition (i.e., Figures 2 and 3), such that older adults recalled and recognized a greater number of TBF items alongside a lesser number of TBR items, relative to younger adults.

As shown in Figures 2 and 3, the graphs depicting recall and recognition are remarkably similar. The comparable findings between tests of recall and recognition were predicted from the item-method approach and suggest that performance differences primarily operate at encoding (Basden et al., 1993; Titz & Verhaeghen, 2010). If performance differences were operating primarily at retrieval (such that older adults were inhibiting the retrieval of TBF items), we would expect a release from inhibition at recognition, such that older adults would recognize a greater proportion of TBF items than they previously recalled. We might also expect differences on the measure of non-recall (i.e., retrieval inhibition) that was included on the final two word lists, of which none were obtained,  $F < 1$ . Thus the current pattern of results suggests that performance differences were operating at encoding, such that items that were sufficiently encoded and remained in the working memory space at recall were the same items that were later recognized.

Results additionally suggest that WMC mediates performance, as participants with greater WMC were better able to resist interference from TBF items while simultaneously and strategically encoding high-value items. This relationship became a greater source of individual differences with increasing age, as WMC was significantly and negatively correlated with recall of TBF items in older adults (i.e., suggesting greater resistance to distracting interference) ( $r = -.503, p < .001$ ), whereas this relationship was not significant in younger adults ( $r = -.230, p > .05$ ).

The working memory measures (i.e., AOSPAN task and Stroop span task) were selected to reflect participants' processing, storage, and inhibitory capacities. These

measures have been found to reflect executive and attentional control capacities (McCabe et al., 2005; Unsworth et al., 2005) and, assuming these capacities are supportive of performance in the value-directed remembering task, one would expect significant correlations between WMC measures and selectivity indices. In particular, WMC was expected to correlate with recall of high-value items and non-recall of TBF items, as both elements were crucial for performance. Correlational analyses confirmed these expectations, as results for the entire sample showed a significant positive correlation between WMC and recall of high-value items ( $r = .701, p < .001$ ) alongside a significant negative correlation between WMC and recall of TBF items ( $r = -.536, p < .001$ ).

Castel and colleagues (2009) made similar predictions in expecting WMC to correlate with performance and used computation and reading span measures to create a composite variable reflective of WMC. WMC was weakly correlated with SI for older adults ( $r = .22, p < .05$ ), and there was no correlation between WMC and SI for younger adults ( $r = .00, p > .05$ ). While restriction of range likely played a role in diluting correlations for younger adults, the value-directed remembering task used by Castel et al. (2009) may not have adequately challenged controlled processing, thereby limiting the strength of relationships with working memory measures.

By increasing the controlled processing demands in the current study such that inhibition is required, the correlations between WMC and SI increase for both older and younger adults ( $r = .596, p < .001$ ;  $r = .317, p < .05$ , respectively). This lends strength to the argument that inhibitory control is supportive of performance, and thus in accord with Hasher and Zacks' (1988) inhibitory deficit hypotheses, selectivity indices were expected to decrease with age alongside declines in the efficiency of inhibitory mechanisms. Results supported this prediction, and WMC was found to mediate this relationship, as evidenced by correlational and hierarchical regression analyses.

However it's important to note that the ability to selectively encode information likely depends upon several interrelated abilities, such as the ability to inhibit distracting

interference, the ability to selectively attend to goal-relevant information, the ability to maintain activation of task goals, the ability to monitor performance across the task, and/or effective binding of words to their respective point-values (Castel, 2007; Titz & Verhaeghen, 2010; Zacks et al., 1996). Although processing speed may play a contributory role, hierarchical regression analyses suggest that WMC accounts for 44.7% of the variance in selectivity indices, whereas processing speed failed to account for a significant portion of variance after controlling for WMC ( $\Delta R^2 = .010$ ).

As per the associative deficit hypothesis (Naveh-Benjamin, 2000; Naveh-Benjamin, Brav, & Levy, 2007), it may be the case that older adults were impaired in their ability to bind words to their associated point values, thereby resulting in source memory confusion and greater recall of TBF items. This may have also contributed to the greater number of intrusions (i.e. recall of previous items on subsequent word lists) by older adults, such that reduced accessibility or cohesion of bindings resulted in impaired recollection across word lists. However, optimal performance in the current task requires participants to actively attend to high-value items while concurrently inhibiting interference from negative-value items, and thus performance appears to be more greatly dependent upon efficient inhibitory control and less dependent upon binding each word to its respective point value. Further, it may be the case that inhibitory processes support performance by suppressing the binding of irrelevant information while concurrently enhancing bindings of more relevant information (Bäuml, Pastötter, & Hanslmayr, 2010). In this manner, the current pattern of results best align with Hasher and Zacks' (1988) inhibitory deficit hypothesis, such that the efficiency of inhibitory control mechanisms appears to decline with age.

When considering the entire sample ( $N = 96$ ), results indicate a strong positive correlation between SI and recall of high-value items ( $r = .932, p < .001$ ) alongside a strong negative correlation between SI and recall of TBF items ( $r = -.865, p < .001$ ), thus providing additional evidence for the role of controlled attention in value-directed

remembering. These findings align with results from hierarchical regression analyses and further suggest that efficient inhibitory control supports performance in tasks of selective encoding, as optimal selectivity indices depend upon both the recall of high-value items and the suppression of TBF items.

Under the inhibitory framework, words that are inhibited at encoding and subsequently cleared from the working memory space would then be unavailable at recognition (Zacks et al., 1996). Results support this assertion, as recognition data closely mirrored that of recall data. Additionally, age-related declines in selectivity suggest declines in the efficiency of inhibitory mechanisms, such that a greater proportion of TBF items retained access to the working memory space of older adults, thereby limiting available resources for greater processing of TBR items. This was evidenced by the significant Age x Item-Type interactions for recall and recognition, such that older adults demonstrated a decline in the directed forgetting effect (i.e., greater recall and recognition of TBF items alongside lesser recall and recognition of TBR items), relative to younger adults. The role of inhibitory control was additionally evidenced by the correlations between WMC, recall of high-value items, and non-recall of TBF items (all of which contributed to selectivity indices and strengthened in association alongside advancing age). As parsimony would prefer an overarching framework encompassing several others, the findings of the current study appear to best align with Hasher and Zacks' (1988) inhibitory deficit hypothesis.

The current study is unique in that it adds a valuation component to prior studies of directed forgetting. Nevertheless, results align nicely with previous studies of directed forgetting using the item-method approach, such that performance remains comparable between tests of recall and recognition. Directed forgetting performance is thought to be supported by inhibitory mechanisms, such that inhibition operates to suppress or limit processing of TBF information in order to preserve cognitive resources for processing

more valuable information (Zacks et al., 1996). However, debate remains as to whether directed forgetting is reflective of active or passive processes.

Passive theorists suggest that TBF items simply decay from working memory due to a lack of rehearsal, whereas active theorists suggest that this information is actively suppressed by the use of inhibitory control mechanisms (Fawcett & Taylor, 2008). In exploring whether executive control operates during tasks of directed forgetting, Paz-Caballero and colleagues (2004) used the item-method approach and examined event-related potentials (ERPs) at the time an item's cue was received. Assuming directed forgetting is reflective of active processes, one would expect activation in brain regions associated with controlled processing. One would also expect greater activation for occurrences when the TBF item was successfully inhibited versus occurrences when the TBF item was later recognized. Results confirmed these expectations, as successful directed forgetting resulted in greater activation in the superior/middle frontal gyrus and inferior frontal gyrus, which have been implicated in effortful processing tasks. This suggests that directed forgetting is an active process, reflecting controlled cognition and active suppression of TBF information (Paz-Caballero & Jiménez, 2004).

In a similar investigation of directed forgetting with the item-method approach, Wylie and colleagues (2008) collected fMRI and behavioral recognition data and found increased activation in the superior frontal gyrus and hippocampus when participants successfully engaged in intentional (i.e., directed) forgetting. The activation of these areas implicated in executive control contrasted with patterns of activation when participants unintentionally forgot certain items, again suggesting that directed forgetting is an active, goal-driven process. In considering inhibitory control similarly as an active, goal-directed process that serves to filter the contents of working memory, inhibition appears to support directed forgetting performance in the current task by suppressing irrelevant information while maintaining activation of the most relevant information.

Zacks and Hasher (1997) suggest that controlled attention recruits both inhibitory and excitatory mechanisms to efficiently limit the contents of working memory to goal-relevant information. As was found in the case of garden path sentences and in previous studies of directed forgetting (e.g., Andrés et al., 2004; Hartman & Hasher, 1991; Zacks et al., 1996), excitatory mechanisms appear to remain intact with age, whereas inhibitory mechanisms appear to decline in efficiency. These inhibitory mechanisms are thought to control what information gains access to working memory as well as what information is deleted from working memory, so as to keep the working memory system operating as optimally as possible. Therefore, a decline in the efficiency of inhibitory mechanisms also limits the extent to which excitatory mechanisms can operate, as optimal performance requires the deletion of TBF items alongside active processing of TBR items. Given that the primary distinction between the current study and that of Castel et al. (2002, 2007, 2009) was the inclusion of an inhibitory task demand, the current pattern of results appear to best align with Hasher and Zacks' (1988) inhibitory deficit hypothesis and suggest that efficient inhibition is supportive of performance in tasks of selective encoding.

### **Arousal and Valence**

Results of the current study also lend support to socioemotional selectivity theory, which predicts an increased preference for directing resources in an emotionally-meaningful manner as one's remaining timeline becomes increasingly salient (Carstensen, 1995). Carstensen and Mikels (2005) suggest that this time-restrictive quest for emotional satisfaction results in a bias of older adult's attentional and memory resources in favor of positive material, even at the expense of not attending to other task-relevant items. Similarly, Mather and Knight (2005) found that older adults exhibit a preference for attending to positive items while limiting their attention to negative items, and the results of the current study are in accord.

Current findings suggest that older adults more greatly attend to emotionally-salient items, as older adults recalled a greater proportion of high-arousal items, relative to younger adults. Results are additionally supportive of an age-related positivity bias, as this relationship was primarily driven by older adults' greater recall of positive items, relative to younger adults. There were no age differences in recall of negative items. However in analyzing the composition of intrusions, the greatest proportion of older adults' intrusions consisted of negative items. This suggests that previously-relevant negative items remained active in the working memory space of older adults (despite a preference for recalling positive items) and may have depleted resources for greater encoding of goal-relevant items. That is, with less efficient clearing of goal-irrelevant items from working memory, older adults may have faced additional limitations posed by a cluttered working memory space.

### **Limitations**

High-arousal items were included in the current study to manipulate the degree of distracting interference posed by the experimental and control conditions. Assuming high-arousal items operate to garner processing priority, it was expected that assigning these items to negative point values (i.e., TBF items) in the experimental condition would more greatly challenge the inhibitory capacities of participants. That is, participants would have to resist additional distracting interference posed by these arousing TBF items while maintaining activation of high-value items. In the control condition, high-arousal and neutral-arousal words were randomly assigned throughout the 18 positions, and this was intended to deter participants from developing a strategy of simply inhibiting or ignoring any word that seemed arousing or otherwise salient. However, the lack of performance differences between conditions suggests that high-arousal items in both conditions may have interfered with the encoding of neighboring neutral items, thereby preventing scores in the control condition from exceeding those in the



experimental condition. Unfortunately the randomized nature of word presentation disallowed for a post-hoc investigation of order effects, but it would be useful for future studies to disentangle this relationship.

The results of MacKay et al. (2004) (wherein taboo words were incorporated in a traditional Stroop task) suggest that the inclusion of taboo words impairs recall of neutral words presented immediately before or after the arousing word. MacKay and colleagues further suggest that these taboo words abruptly overtake cognitive binding mechanisms, thereby hindering the encoding and retrieval of neighboring neutral words. This is relevant to the current study in that high-arousal items may have similarly interfered with the encoding of neighboring neutral items, irrespective of the condition (i.e., experimental vs. control). Given that words were randomly assigned to point values in the control condition, it may have been the case that seeing a high-arousal word with a point value of 4, for example, resulted in the encoding and subsequent recall of this lower-value item, whereas attention would have otherwise remained focused on higher-value items in the absence of arousing stimuli. A follow-up study is currently being conducted with pure lists consisting entirely of neutral-arousal, neutral-valence words, and this should help explore age differences in selectivity outside of any confounding effects of arousal and valence.

For the final two word lists, participants were additionally asked if there were any words they recalled but chose not to write down because they knew it would hurt their score. This was included as a measure of retrieval inhibition to examine whether participants were withholding words at retrieval, which would dilute the argument that performance differences were operating at encoding. However, no age differences were obtained,  $F < 1$ , and both groups were near floor on this measure. This suggests that performance differences were operating primarily at encoding, as would be expected from the item-method approach. Although the inclusion of this measure was useful in differentiating between selective encoding and retrieval inhibition, it may have hindered

performance on the final two word lists, as it broke participants' concentration and disrupted the flow of the task. Participants may have anticipated being asked again on the last word list if there were any words they remembered but chose not to write down, as recall performance suffered for both age groups. The current follow-up study does not employ this measure of non-recall and is expected to allow for a more accurate assessment of selectivity across the task.

An additional limitation of the current study is its strength of differentiation between theories of age-related decline. Although the study included indices of speed of processing and found WMC to account for variation in performance over and above that of processing speed, it would be useful for future studies to incorporate measures of associative binding as well. Perhaps the recognition task could be modified, such that participants are first asked whether the word is 'old' or 'new' and are then asked to enter the point value corresponding to that particular item. This would allow for an investigation of the degree to which older and younger adults bind words to their respective point values during encoding. In order to investigate the extent of binding precision, half of participants could be asked to recall a specific point value, whereas the other half of participants could be asked to select an appropriate point value range (i.e., negative-value, low-value, high-value). This would help examine the degree to which participants bound each word to a specific or generic point value and would also help evaluate whether differences in binding exist for words of a particular point value. It may be the case that participants engage in more gist-based encoding strategies, binding items to generic tags (e.g., "high value," "important," "to remember," "to forget"), rather than engaging resources to bind each word to a specific point value.

Castel et al. (2007) similarly asked participants to recall either the point value or the point value range and found that older and younger adults were equally as precise when determining the point value range for high-value items but that younger adults were more precise in recalling specific point values. However, older adults may have been

more inclined to select point value ranges due to a lack of certainty or preference for a larger selection set. By counterbalancing the response options such that half of participants respond with specific point values and half of participants respond with point value ranges, we can begin to tease apart these differences. This would also allow for an evaluation of whether precision of binding has an impact on performance as well as whether differences exist between age groups or participants of varying working memory spans. Given that performance in the current task is not dependent upon precise binding of each word to its point value, it may be the case that gist-based encoding strategies are more beneficial to performance, as these strategies may conserve cognitive resources and facilitate greater encoding of high-value items.

### **Conclusions**

The current study is the first known incorporation of directed forgetting and value-directed remembering in the study of age, working memory, and controlled attention. Given that age differences in selectivity were obtained, it is useful to consider the primary distinctions between the current study and that conducted by Castel and colleagues (2009), wherein no age differences were found. The current study increased task demands by introducing an inhibitory task demand in the form of value-directed forgetting. In considering directed forgetting as an active cognitive process, this inclusion was expected to increase reliance upon executive functioning. The current study also increased task demands by incorporating arousing stimuli, by extending each word list from 12 items to 18 items, and by increasing the viewing time for each word from two seconds (as per Castel et al., 2009) to three seconds. The extension of word lists (both in length and in viewing time) extended the amount of time participants must actively attend to each word list while maintaining task goals and inhibiting distracting interference.

These increases in task demands require controlled processing, and it is therefore not surprising that a greater relationship between WMC and performance was found. As

noted by Engle, Kane, and Tuholski (1999), controlled processing is required for the maintenance of task goals in the face of interference, and research suggests age-related declines in controlled processing tasks (Hartman & Hasher, 1991; McCabe et al., 2005; Park & Payer, 2006). Thus it is also not surprising that age differences in selectivity were found, as the current task requires participants to inhibit the processing of TBF items while maintaining activation of higher-value items, despite possible interference from arousing items of differing point values. Although age differences could arguably be accounted for by deficits in associative binding (Naveh-Benjamin et al., 2007), it could likewise be argued that inhibitory control supports optimal binding of goal-relevant items, and thus parsimony would suggest that Hasher and Zacks' (1988) inhibitory deficit hypothesis is most amenable to the current pattern of results.

Taken together, the above results suggest that older adults were not impaired in their ability to comply with task demands but were simply impaired in their efficiency of doing so, as would be expected from Hasher and Zacks' (1988) inhibitory deficit hypothesis. That is, older adults displayed impaired selectivity, relative to younger adults, yet were proficient in following task demands. The impaired efficiency of inhibitory processes was further evidenced by older adults' greater recall and recognition of TBF items alongside lesser recall and recognition of TBR items, relative to levels of younger adults. The findings of the current study additionally suggest that directed forgetting is reflective of active control processes, as inhibition of TBF items alongside maintenance of TBR items requires executive control (Paz-Caballero & Jiménez., 2004; Wylie et al., 2008), and WMC was found to mediate performance.

As supported by Engle and Kane (2004), individual differences of WMC are most predictive of performance in controlled, attention-demanding tasks. Accordingly (and given the increase in task demands), age-related impairments in selectivity were mediated by WMC, such that individuals with greater WMC were better able to maintain activation of high-value items while suppressing activation of TBF items, relative to individuals

with lesser WMC. In considering age-related declines in frontal lobe functioning (West, 1996), directed forgetting's reliance upon active processing (Paz-Caballero et al., 2004; Wylie et al., 2008), and the results of the current study (i.e., age-related increases in processing of task-irrelevant items alongside decreases in processing of task-relevant items), it appears as though impaired inhibition depletes working memory resources necessary for optimal and strategic encoding of information.

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